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VI. Controlling mechanisms

Sources of Oxygen demand

Total, carbonaceous and nitrogenous BOD were compared in order to determine the relative contribution of each to oxygen demand. These comparisons were made in order to address the question:

Question: What is the oxygen demand from algal biomass compared with other oxygen demanding substances?

Answer: The oxygen demand in the DWC was primarily produced by nitrogenous materials and was poorly correlated with algal biomass.

The oxygen demand in total BOD tests was primarily produced by the decomposition of nitrogenous material by nitrifying bacteria or nitrification. Carbonaceous BOD consistently accounted for 1-2 mg/L of the total BOD at stations 24, 43 and 51 and was a small percent of the total BOD that reached 6 mg/L (Fig. VI-1). The carbonaceous BOD decreased seasonally and contrasted with total BOD that increased seasonally.

The seasonal increase in total BOD was positively correlated ($p < 0.01$) with ammonia and total Kjeldahl nitrogen at station 24 and station 43 in the DWC and station 51 in the upper San Joaquin River (Fig. VI-2). The importance of ammonia to the seasonal increase in total BOD₁₀ throughout the DWC was supported by both high correlation coefficients and consistent patterns among correlation coefficients at stations 24, 43 and 51 (Tables VI-4 a-c). Total BOD₁₀ was most highly correlated with nitrogenous BOD (NBOD) and ammonia concentration among the 15 variables tested. Ammonia concentration was often high at these stations and seasonally increased with high load from the Stockton Regional Water Control Facility in September through November (Fig. VI-3). Total Kjeldahl nitrogen measures both ammonia and non-ammonia nitrogen sources and increased in association with the seasonal increase in ammonia concentration.

Total BOD₁₀ was not associated with algal biomass at stations 24, 43 or 51 (Table VI-4 a-c). Total BOD, ammonia, nitrogenous BOD and total Kjeldahl nitrogen were negatively or non-significantly correlated with chlorophyll *a* or phaeophytin concentration. Even the correlation between chlorophyll *a* or phaeophytin concentration and carbonaceous BOD was non-significant except at station 43.

In contrast, total BOD was not significantly correlated with dissolved ammonia concentration at station 50 in the Turning Basin where dissolved ammonia concentration was usually low and oxygen demand was dominated by algal biomass. Ammonia concentration was usually 2 times lower and chlorophyll *a* concentration was 2 times higher at station 50 than downstream in the DWC (Fig. VI-2; Table VI-4 d. Here carbonaceous BOD₁₀ usually comprised over 50% of the total BOD₁₀ and was

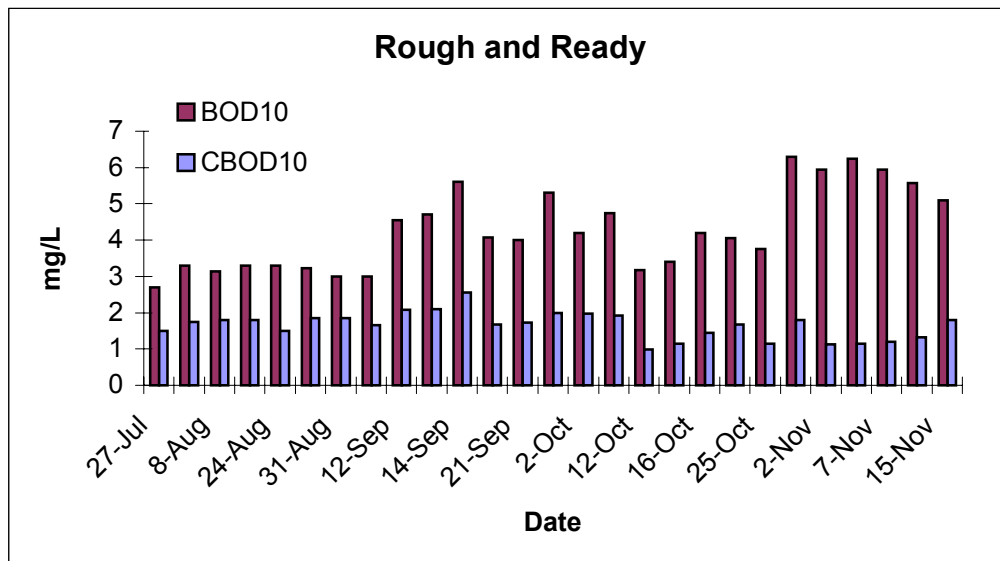
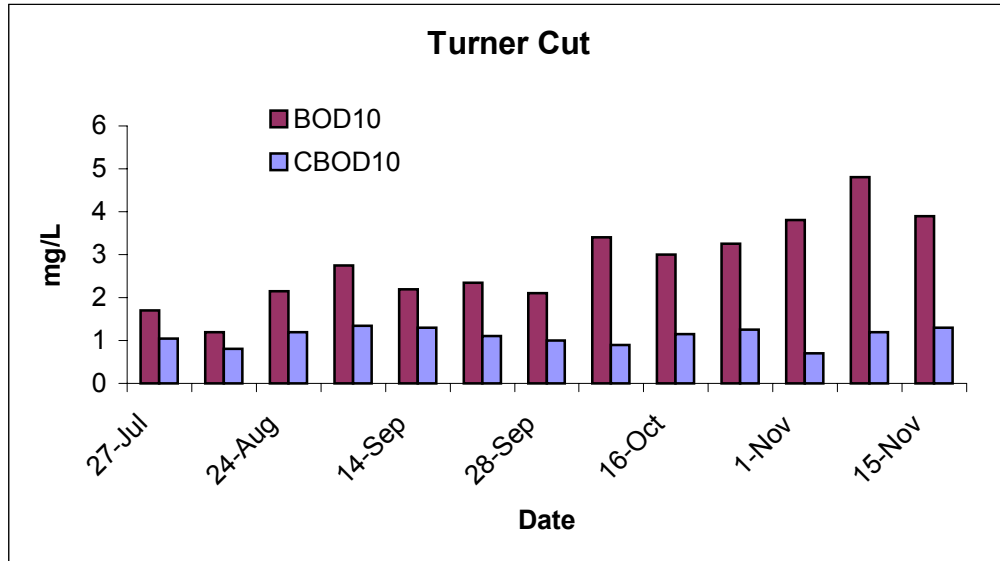
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positively correlated with total BOD, Kjeldahl nitrogen, chlorophyll *a* and phaeophytin concentration.

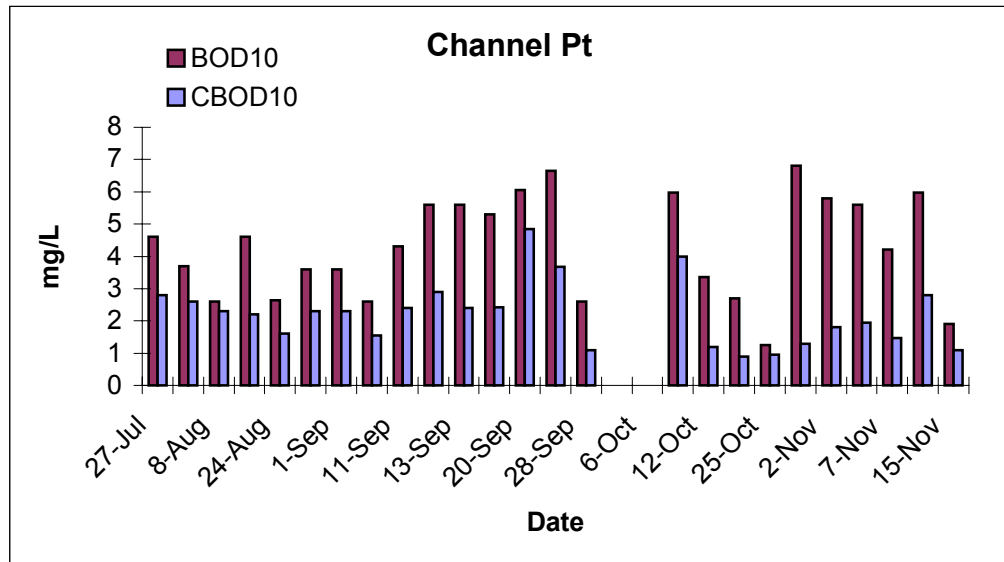
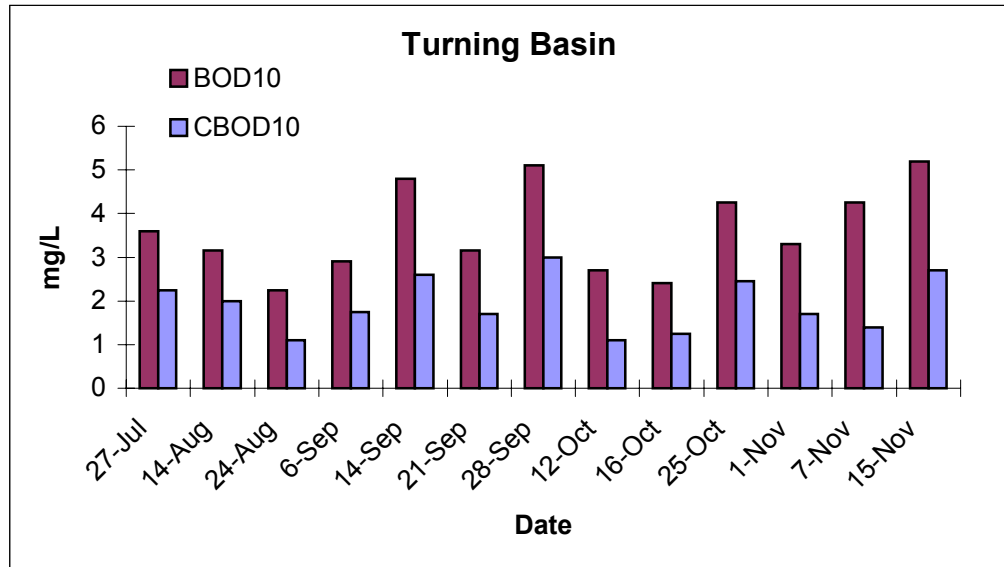
Settling rate studies confirmed the relatively small contribution of carbonaceous BOD to the total BOD and dominance of nitrogenous BOD to the total BOD in the DWC. In addition, separate BOD tests on suspended particles versus water column samples indicated the total BOD was driven by the soluble phase (G. Litton, personal communication).

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Fig. VI-1. Comparisons of total and carbonaceous BOD of water samples in the DWC at Turner Cut and Rough and Ready Island and upstream input stations at Turning Basin and Channel Point. Nitrogenous BOD is the difference between the two.

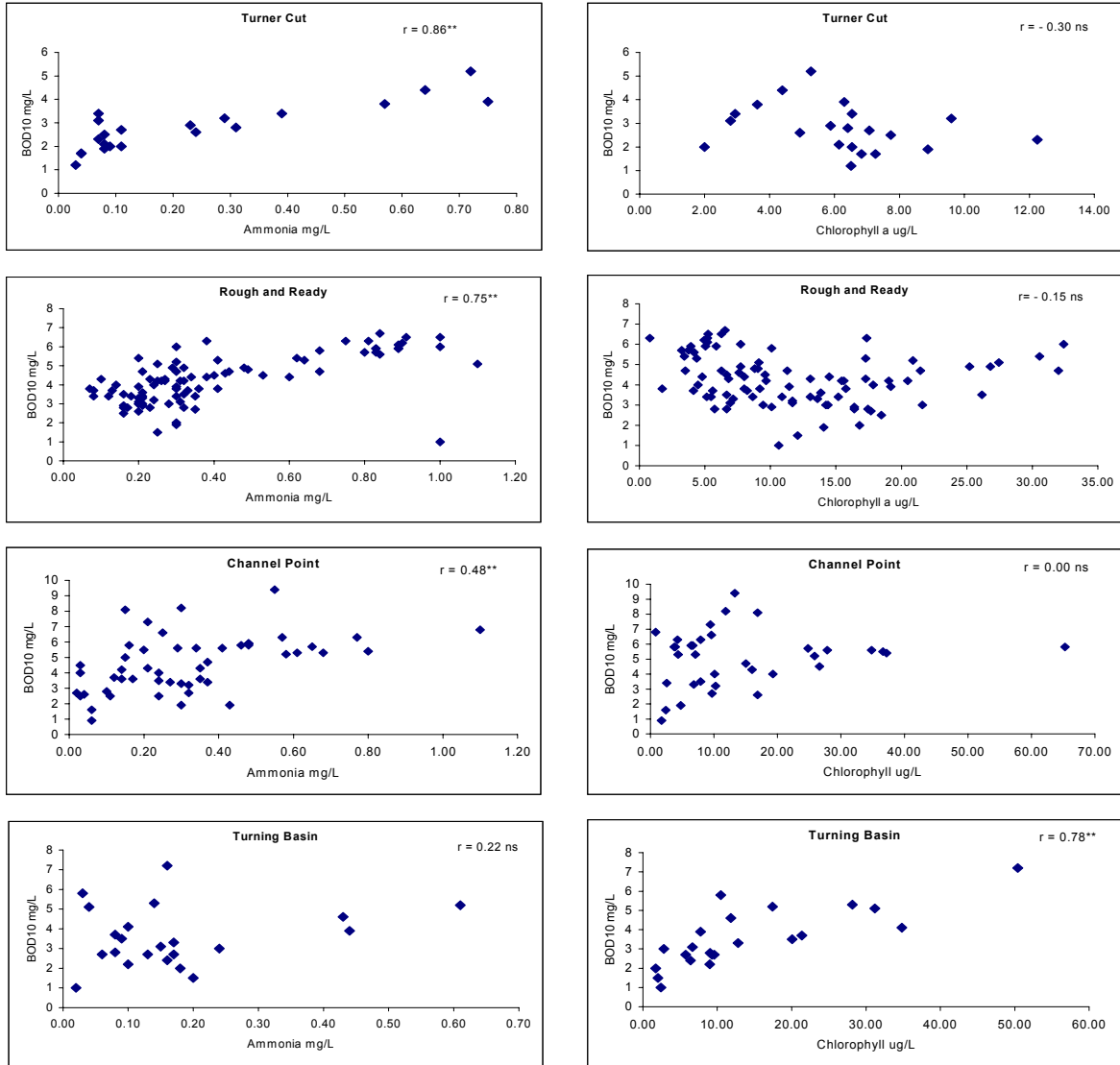


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Fig. VI-2. Association between total BOD and either ammonia or chlorophyll *a* concentration for four stations in and around the DWC during 2000.



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Table VI – 4 a. Pearson correlation coefficients calculated among water quality variables measured at Turner Cut station 24 between July and November 2000. Coefficients are significant at either the 0.05 level (regular type) or 0.01 level (bold type).

	ammonia	chlorophyll	BOD10	BOD5	CBOD5	CBOD10	chloride	dissolved organic carbon	nitrate	orthophosphate	phaeophytin	total keldahl nitrogen	total organic carbon	total phosphorus	total suspended solids	volatile suspended solids	NBOD10
ammonia			.86					.61			-.69	.76	.58		-.52	-.56	.89
chlorophyll									.46								
BOD10	.86			.62								.77	.65		-.48	-.46	.97
BOD5			.62		.44		-.44										.57
CBOD5				.44		.70											
CBOD10					.70												
chloride				-.44				.57	.56					.46			
dissolved organic carbon	.61		.50				.57				-.62	.61	.76	.68	-.55	-.55	.48
nitrate		.46					.56										
orthophosphate											-.58						
phaeophytin	-.69						-.62		-.58			-.43			.44	.49	-.44
total keldahl nitrogen	.76		.78				.61						.43		-.44	-.48	.78
total organic carbon	.58		.65				.76			-.43	.70			.46	-.65	-.61	.68
total phosphorus							.68										
total suspended solids	-.52		-.48				-.53			.44	-.44					.91	-.55
volatile suspended solids	-.56		-.46				.85			.49	-.48	-.61			.91		-.54
NBOD10	.89		.97		.57		.48			-.44	.77	.68			-.55	-.54	
NBOD5			.51	.88			-.47										.55

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Table VI –4 b . Pearson correlation coefficients calculated among water quality variables measured at Rough and Ready Island station 43 between July and November 2000. Coefficients are significant at either the 0.05 level (regular type) or 0.01 level (bold type).

	ammonia	chlorophyll	BOD10	BOD5	CBOD5	CBOD10	chloride	dissolved organic carbon	nitrate	orthophosphate	phaeophytin	total keldahl nitrogen	total organic carbon	total phosphorus	total suspended solids	volatile suspended solids	NBOD10	
ammonia		-.45	.75		-.27	-.26	.42	.71		.23	-.36	.53	.78					.84
chlorophyll	-.45				.52	.58			.34		.53							-.41
BOD10	.75			.47							-.25	.54						.91
BOD5			.47		.51	.44	-.48		-.23									.28
CBOD5	-.27	.52		.51		.79	-.22		-.37			-.26						-.21
CBOD10	-.26	.58		.44	.79				-.31		.44				.45	.45		-.25
chloride	.42			-.48	-.22				.33			.55			.26	.27		
dissolved organic carbon																		
nitrate																		
orthophosphate	.23											.23						
phaeophytin	-.36	.53	-.25			.44						.28		.24	.68	.68		-.44
total keldahl nitrogen	.54		.54		-.26		.55			.23	.28			.35	.53	.52		.51
total organic carbon																		
total phosphorus											.24	.35			.63	.63		
total suspended solids						.45	.26				.67	.53		.63		.99		
volatile suspended solids						.45	.27				.68	.52		.63	.99			
NBOD10	.84	-.41	.91	.28	-.21	-.25					-.44	.51						
NBOD5			.47	.86			-.43				-.28							.44

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Table VI – 4 c. Pearson correlation coefficients calculated among water quality variables measured at Channel Point station 51 between July and November 2000. Coefficients are significant at either the 0.05 level (regular type) or 0.01 level (bold type).

	ammonia	chlorophyll	BOD10	BOD5	CBOD5	CBOD10	chloride	dissolved organic carbon	nitrate	orthophosphate	phaeophytin	total keldahl nitrogen	total organic carbon	total phosphorus	total suspended solids	volatile suspended solids	NBOD10
ammonia		-.34	.48	.46			.39				-.31	.79		.34			.79
chlorophyll	-.34										.58						
BOD10	.48			.89	.38	.74						.33					.69
BOD5			.87			.86											.33
CBOD5	.46		.38						-.35			.29					.39
CBOD10			.74	.86													
chloride	.39								.55			.47					
dissolved organic carbon	.56																
nitrate					-.35		.55										.38
orthophosphate	.41													.43			
phaeophytin	-.31	.58															-.32
total keldahl nitrogen	.79		.33		.29	.47			.41					.55	.34	.28	.55
total organic carbon																	
total phosphorus	.34									.43		.55			.60	.50	.30
total suspended solids												.34		.60		.91	
volatile suspended solids												.28		.50	.91		
NBOD10	.79		.69	.36	.39						-.32	.55		.30			
NBOD5	-.35			.30	-.89					-.28							

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Table VI – 4 d . Pearson correlation coefficients calculated among water quality variables measured at Turning Basin station 50 between July and November 2000. Coefficients are significant at either the 0.05 level (regular type) or 0.01 level (bold type).

	ammonia	chlorophyll	BOD10	BOD5	CBOD5	CBOD10	chloride	dissolved organic carbon	nitrate	orthophosphate	phaeophytin	total keldahl nitrogen	total organic carbon	total phosphorus	total suspended solids	volatile suspended solids	NBOD10	NBOD5	
ammonia																			
chlorophyll																			
BOD10		.78																	
BOD5		.71	.95																
CBOD5		.75	.89	.93															
CBOD10		.79	.90	.91	.98														
chloride																			
dissolved organic carbon																			
nitrate																			
orthophosphate																			
phaeophytin																			
total keldahl nitrogen																			
total organic carbon																			
total phosphorus																			
total suspended solids																			
volatile suspended solids																			
NBOD10																			
NBOD5																			

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Tidal variation

Water quality measurements were compared on each tide during the day in order to determine the impact of tidal day variation on water quality measurements. These data helped to quantify the net tidal day load and answer the questions:

Question: What is the relative contribution of algal biomass from in situ growth and upstream load to oxygen demand in the Stockton Deep Water Channel (DWC)?

Question: What is the oxygen demand from algal biomass compared with other oxygen demanding substances?

Answer: The load of water quality variables varied among tides by a factor of 2 to 4 each day. However, because seasonal variability was also high only ebb and flood tide loads were significantly different for discrete water samples.

Discrete tidal day material export from the DWC was significantly ($p < 0.01$) higher on ebb than flood tide by at least a factor of 2 at station 43. This was true for both spring and neap tide, but there was no significant difference between spring and neap tide.

Light attenuation in water column

Algal growth rates were measured at different light intensities in order to determine the influence of light on the maximum potential for algal growth in the DWC. This is important management information because algae are light limited in the San Joaquin River and management alternatives that affect water clarity could impact algal production rate and the associated oxygen demand. This information was used in the question:

Question: What mechanisms influence the impact of algal load and growth on oxygen demand?

Answer: Light attenuation was an important controlling mechanism for algal growth and oxygen demand. The light in the euphotic zone averaged 18% of surface irradiance. At this low light level algal growth was limited to 25% of its maximum potential.

Method - Algal growth potential at varying light intensities was estimated by dissolved oxygen light/dark bottle incubation of water samples in open-air flow through incubators that utilized ambient surface irradiance and river water to produce the natural diel pattern

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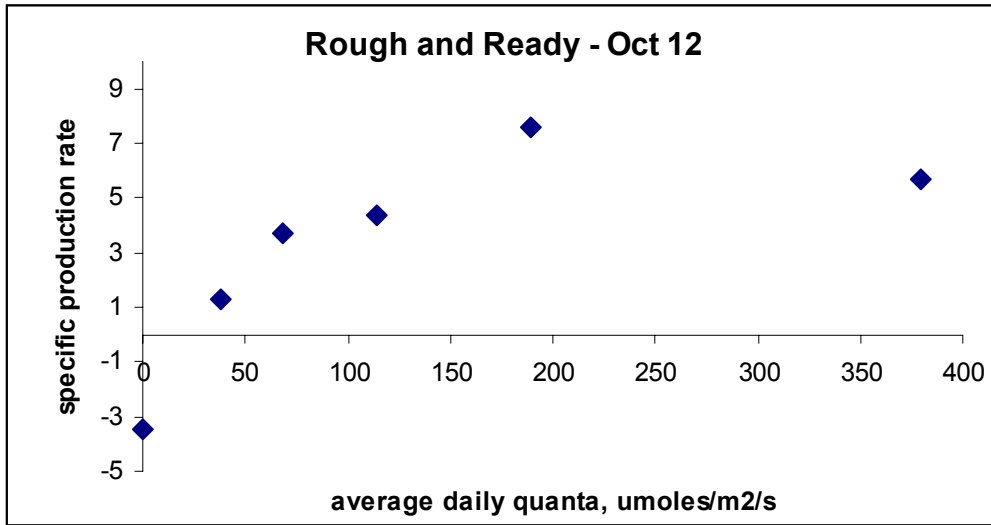
of light and water temperature. Continuous pumping of water from 1-m depth through the incubator coil system maintained water temperature within 0.5 °C of ambient water temperature. Light intensity of replicate water samples was varied by a series of screens to achieve zero to 50 percent of surface irradiance. Diel changes in surface irradiance were measured with an Eppley pyroheliometer and LiCor quantum sensor.

Specific community production rates (ug oxygen / ug chl a / hr) measured at each light intensity were used to generate photosynthesis versus light curves for each day (Fig. VI-3). The threshold of these curves is the maximum specific production rate or assimilation ratio and indicates the maximum algal growth rate at optimum light intensity. The initial slope of the photosynthesis versus light curve (ug oxygen/ ug chl a / hr / umole quanta/ m 2 / s) was used to measure algal response rate to increasing light (Platt and Jassby 1976).

Results - Light severely limited algal growth in the deep water channel. Light extinction was rapid and surface irradiance usually decreased to 1% within a depth of 2-m (Fig. VI-4). Algal photosynthesis only occurs in this portion of the water column called the euphotic zone that was about 2-m throughout the season in the study reach between Turner Cut at station 24 and Rough and Ready Island near station 43 (Fig. VI-5). Maximum specific production rate generally decreased from about 20 to 5 ug oxygen/ug chlorophyll a / hr (Fig. VI-6) and was commonly associated with a daily average light intensity between 25 and 45% of the surface irradiance (Fig. VI-7). This optimum light intensity was well above the 18% average surface light intensity commonly measured in the euphotic zone at station 43. Both the average maximum specific production rate and initial slope of the photosynthesis versus light curve varied seasonally by a factor of 2 to 3 (Fig. VI-8), but similar initial slopes among stations suggested growth of both upstream and downstream algae were equally influenced by light limitation in the DWC.

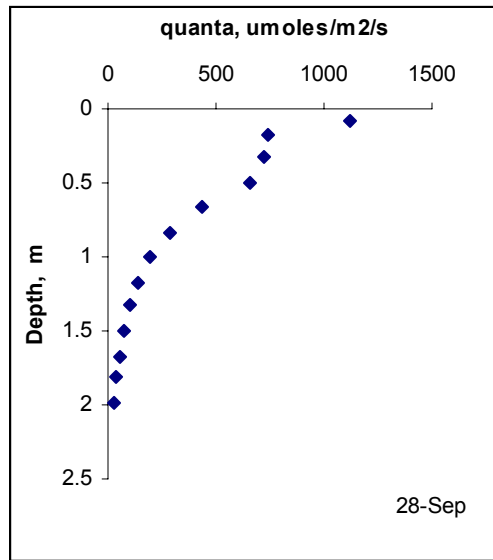
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Fig. VI-3. Characteristic photosynthesis versus average daily light intensity curve plotted for station 43 near Rough and Ready Island. Specific production rate is in units of μg oxygen/ μg chlorophyll *a* / hour.



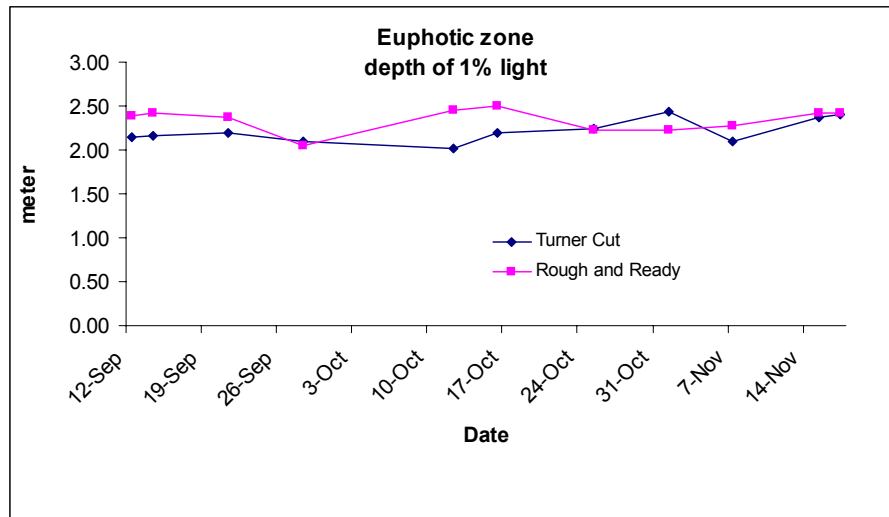
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Fig. VI-4. Characteristic light extinction in the water column at station 43 at Rough and Ready Island measured on September 28, 2000.



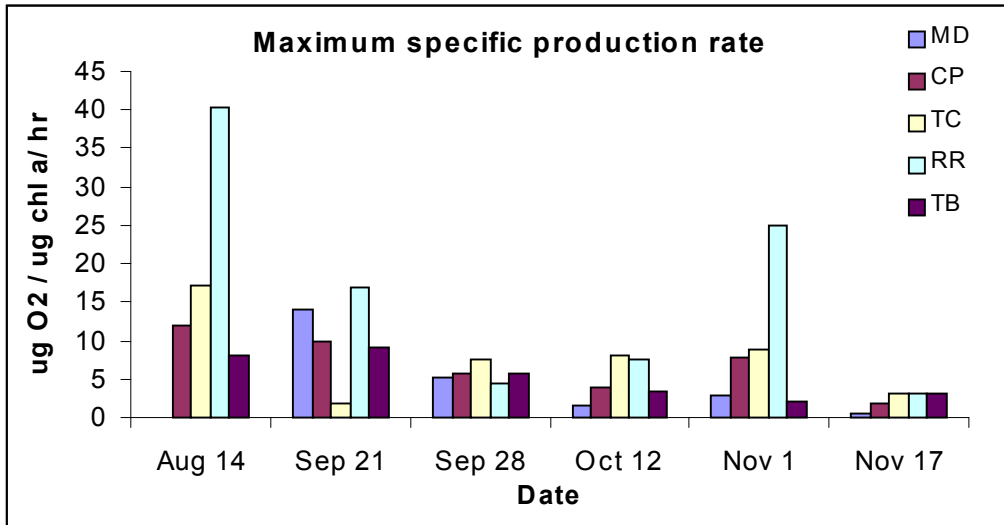
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Fig. VI-5. Depth of euphotic zone or 1% surface light attenuation at station 24 near Turner Cut and station 43 near Rough and Ready Island.



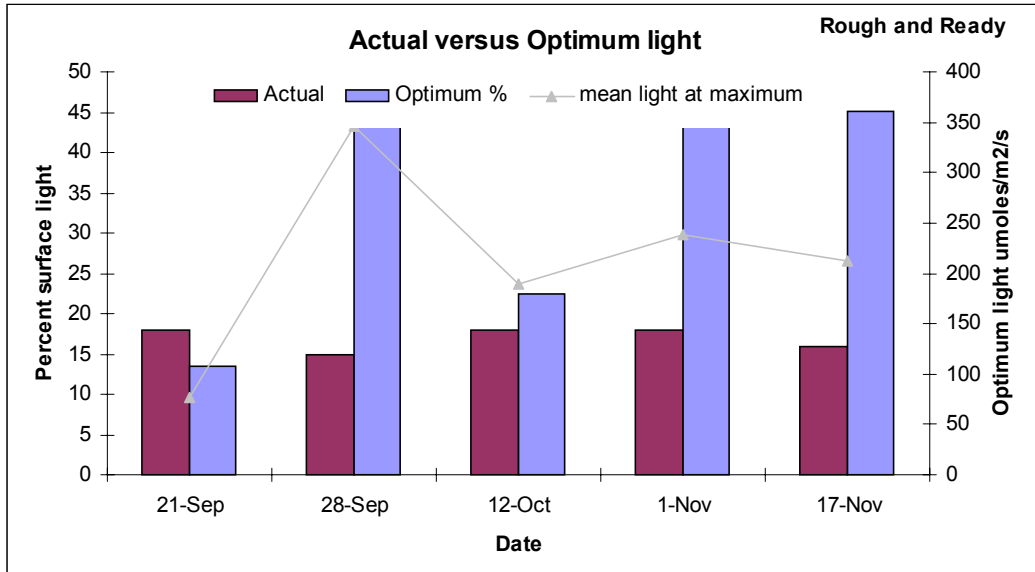
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Fig. VI-6. Maximum specific production rate measured during light saturation experiments for Mossdale (MD), Channel Point (CP), Turner Cut (TC), Rough and Ready (RR) and Turning Basin (TB).



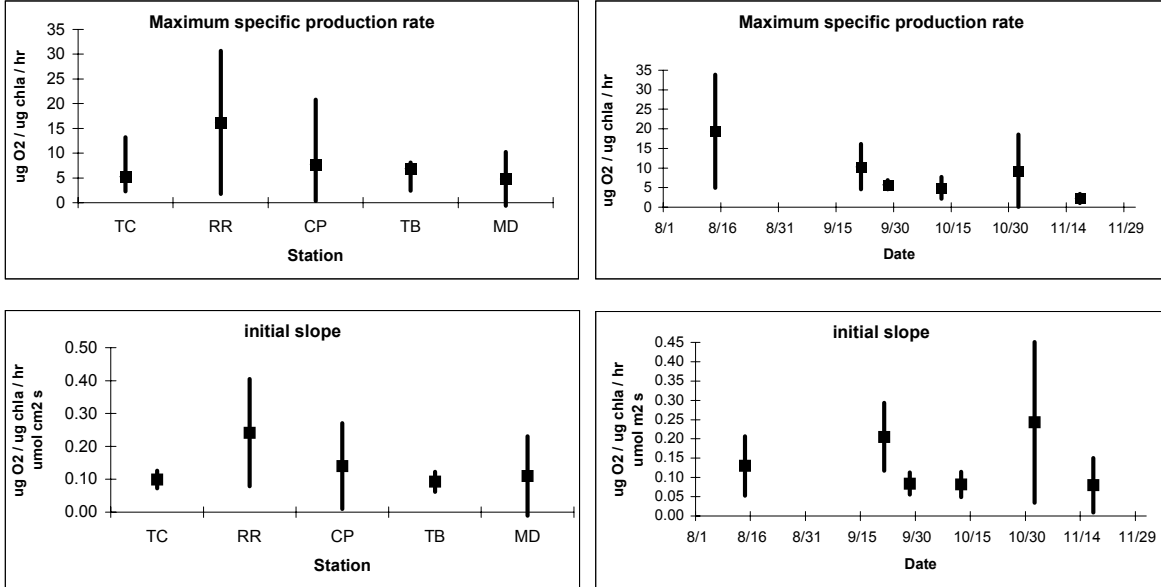
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Fig. VI-7. Actual versus optimal percent surface irradiance for algal growth at station 43 near Rough and Ready Island.



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Fig. VI-8. Average maximum specific production rate and initial slopes measured during light saturation experiments for Mossdale (MD), Channel Point (CP), Turner Cut (TC), Rough and Ready (RR) and Turning Basin (TB).



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Algal species composition

Spatial and temporal variation in algal species composition was used to assess whether algal species composition could be a significant factor in algal growth or oxygen demand. This study element addressed the basic question:

Question: What mechanisms influence the impact of algal load and growth on oxygen demand?

Answer: A highly mixed diatom community comprised the majority of algal biomass in the DWC and all adjoining stations. There was no indication that one input source controlled the algae in the DWC.

Methods

Water samples for algal species identification were collected by Van Dorn sampler and placed in a 50ml amber glass bottle with Lugol's preservative and stain. Species enumeration and identification were done using the Utermohl settling chamber technique (Utermohl 1958) and applied as described in Lehman (1996).

Results

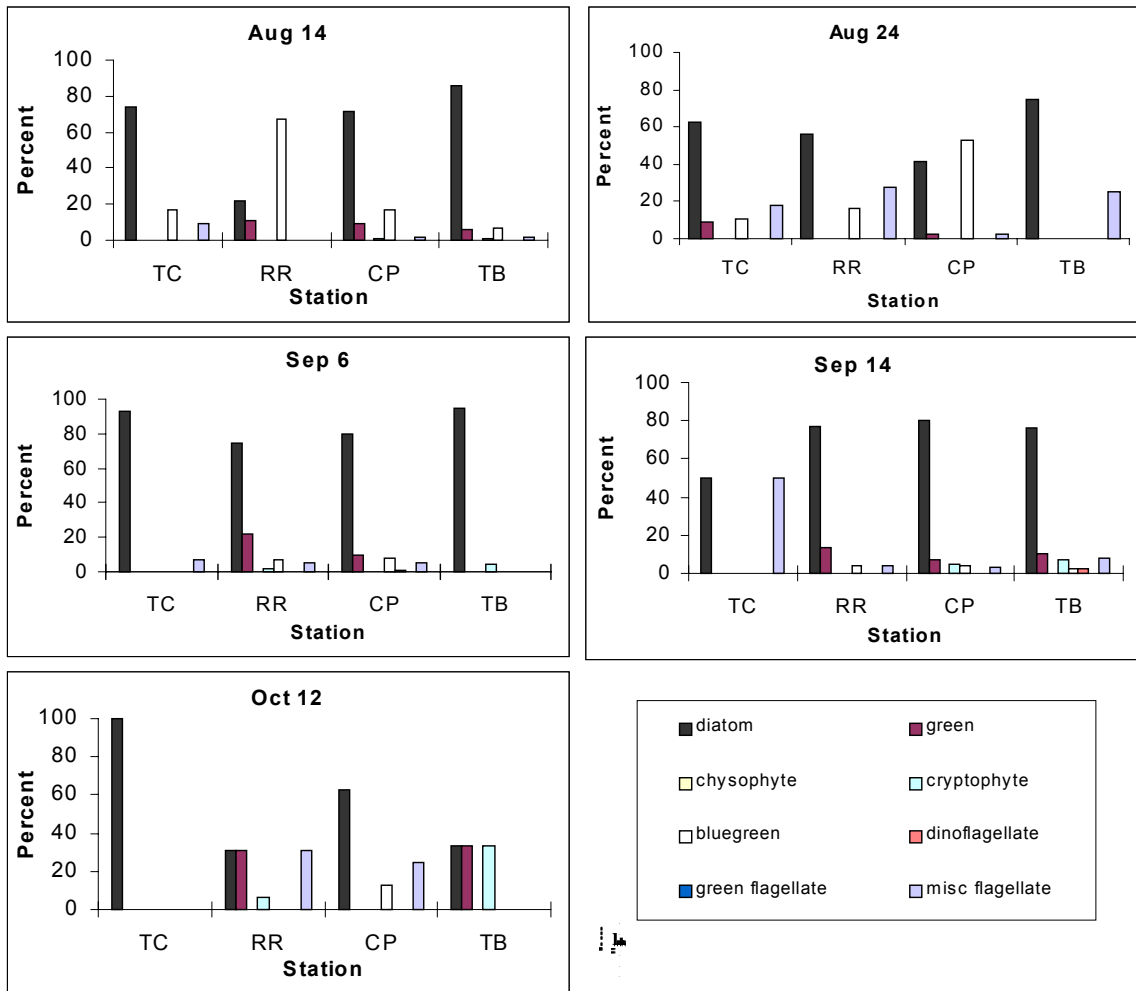
Species composition within and outside of the DWC and was primarily composed of diatoms (Fig. VI-9). Bluegreen algae were sometimes abundant at Rough and Ready Island near station 43 in the DWC and high densities at Channel Point near station 51 suggested bluegreen algae often originated from the upper San Joaquin River. However, bluegreens contributed little to the total chlorophyll *a* biomass because their cell dimensions and associated biomass were small compared diatoms.

The species assemblage of the diatoms and bluegreens was highly mixed in the DWC and adjacent areas. High diversity occurred at Channel Point and the Turning Basin (Fig. VI-10). Common diatom species included *Achnanthes* spp., *Thalassiosira eccentrica*, *Cyclotella* spp., *Coscinodiscus* spp. and *Amphora coffaeiformis*. Abundant bluegreen species were *Anaebaena* spp., *Aphanizomenon flos-aquae*, *Agmenellum* spp. and *Oscillatoria* spp..

Species composition suggested the sources of algae in the DWC at Rough and Ready Island was highly variable. On August 14, the presence of the diatom *Aulacoseira*(*Melosira*) *granulata* at Rough and Ready Island suggested these algae were seeded from Channel Point, but the presence of the bluegreen *Agmenellum* spp. also indicated seeding from the Turning Basin at station 50 (Fig. VI-10). On August 24, the abundance of the diatoms *Achnanthes* spp. and *Amphora coffaeiformis* at all stations suggested the algae were well mixed throughout the region, but the presence of the diatom *Thalassiosira eccentrica* at Rough and Ready Island was probably caused by seeding from station 24 at Turner Cut where it was abundant (Fig. VI-11). On September 6, the diatoms *Achnanthes* spp., *Cyclotella* spp. and *Amphora coffaeiformis* were abundant at all stations, but the bluegreen algae *Oscillatoria* spp. at Rough and Ready could only have originated from Channel Point (Fig. VI-12).

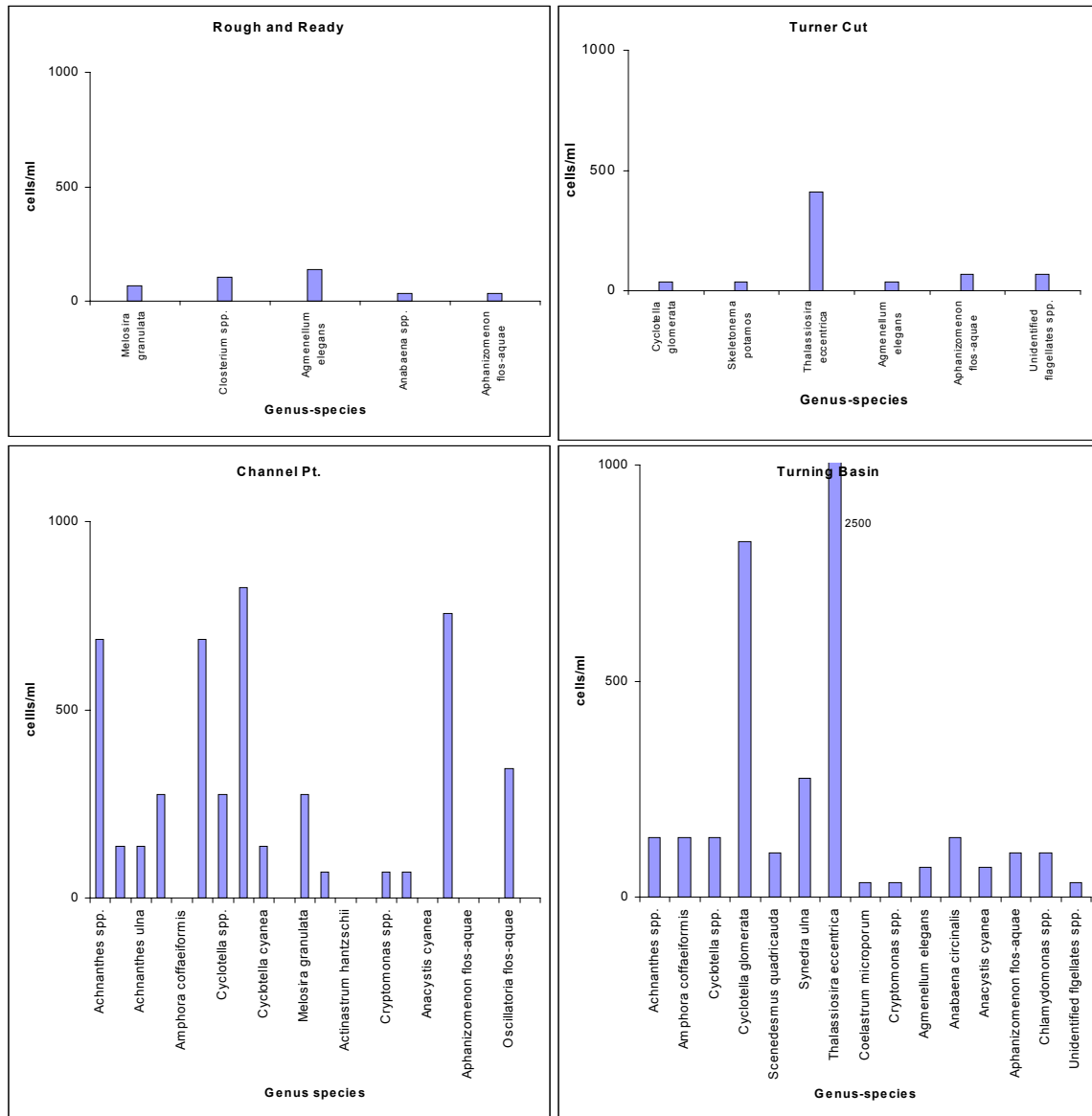
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Fig. VI-9. Representative percent composition by algal group among months for station 24 near Turner Cut (TC), station 43 near Rough and Ready Island (RR), station 50 near Turning Basin (TB), and station 51 upstream of Channel Point (CP).



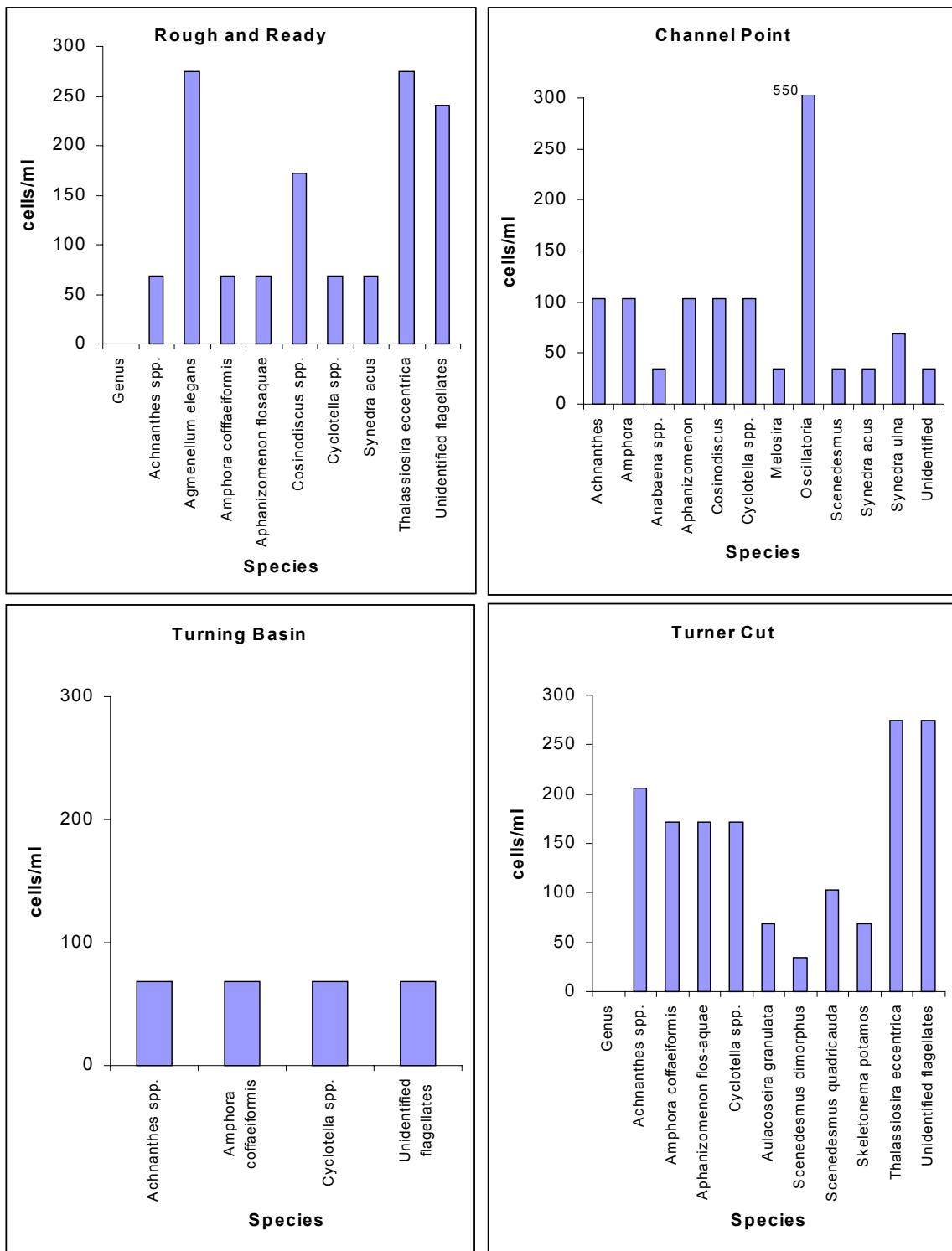
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Fig. VI-10. Algal species composition measured in the DWC and adjoining stations on August 14, 2000.



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Fig. VI-11. Algal species composition and density in the DWC and input stations measured on August 24, 2000.



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Fig. VI-12. Algal species density and composition in the DWC and nearby measured on September 6, 2000.

